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THE GEOLOGY OF NEW YORK CITY AND VICINITY

FORDHAM GNEISS

By CHESTER A. REEDS

GUIDE LEAFLET SERIES No. 56

Third Edition

April, 1930

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GEOLOGY OF NEW YORK CITY AND VICINITY

By CHESTER A. REEDS
Curator of Geology and Invertebrate Palæontology

The American Museum of Natural History
Guide Leaflet No. 56
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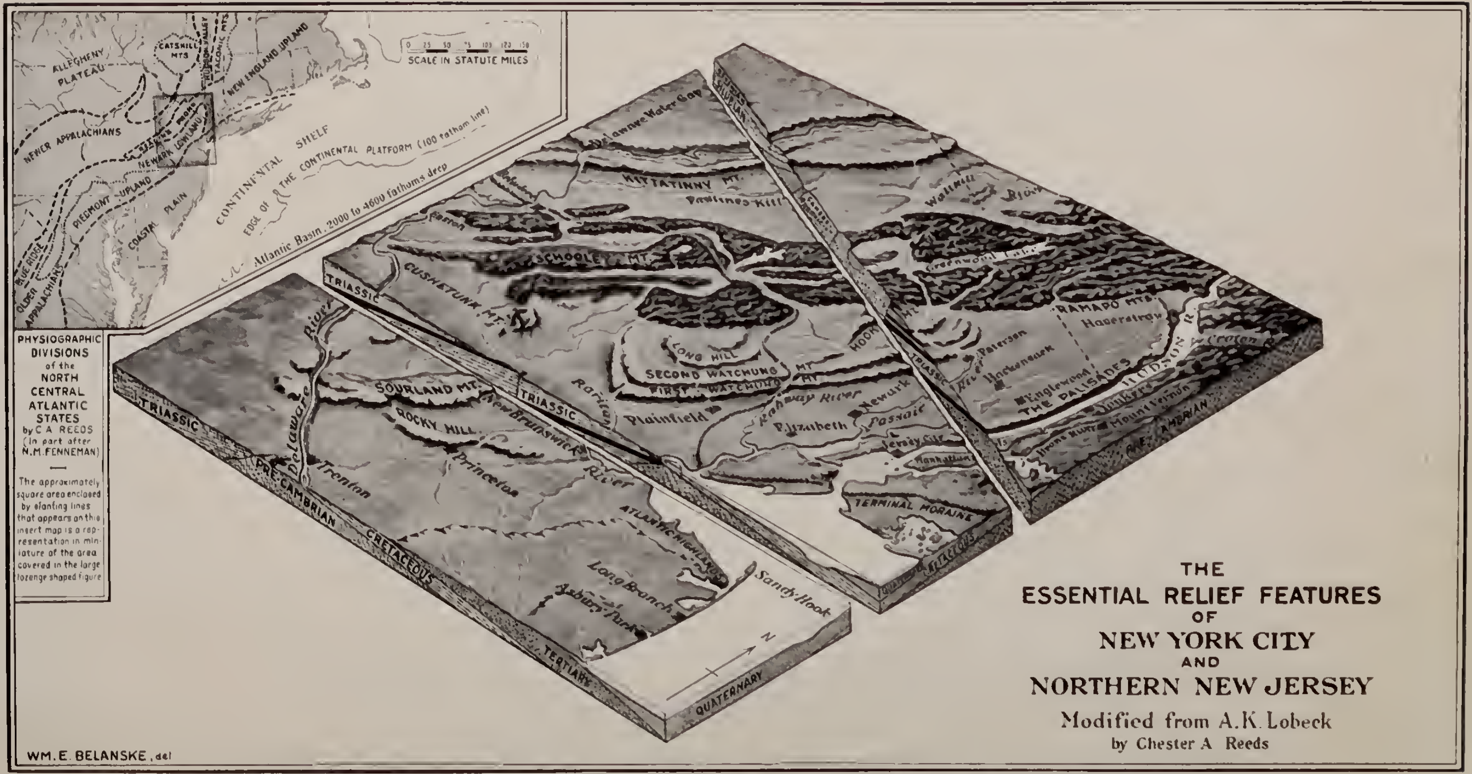

DIAGRAMMATIC RELIEF MAP OF NEW YORK CITY AND ADJOINING AREAS

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Geology of New York City and Vicinity

By CHESTER A. REEDS
Curator of Geology and Invertebrate Palæontology

RELIEF FEATURES

The relief features of the New York City district consist of several distinctly different types, which have been developed by natural forces on rocks of unequal hardness. Some of the rocks are unconsolidated sands and muds and are of comparatively recent date; others are stratified with alternating hard and soft beds, which have been tilted or slightly folded and are older; still others of the same origin but far older have been so much altered and deformed during certain geologic periods that they have become crystalline and entirely changed in appearance, that is, metamorphosed. Volcanic rocks thick and homogeneous in character have also been injected into the area at different times, some very early, others later, but none very recently. These and some of the crystalline ones form the most resistant ridges. The distribution of the rocks is in the form of belts with a prevailing northeast-southwest direction.

The essential relief features and physiographic provinces of the area are shown in a graphic manner on the relief map, *frontispiece.* They may be summarized as follows:

1. The continental shelf, which represents the submerged margin of the continent, extends eastward from the New Jersey shore for about 100 miles to the 100 fathom line. Beyond that point the sea floor drops rapidly to the great and extensive oceanic depths of 2000–4600 fathoms.

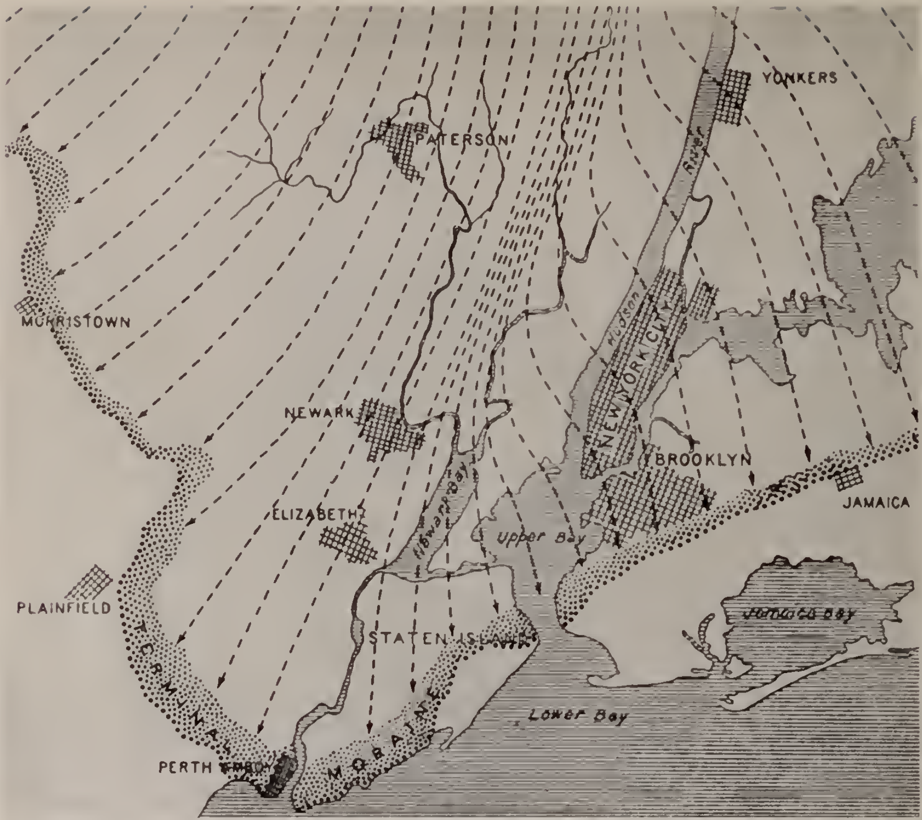
2. The Coastal Plain is that portion of the former submerged continental shelf which has been raised above the sea without apparent deformation. Three well defined elements of this plain appear:

(a) Its inner lowland, partly drowned in Long Island Sound, Lower New York and Sandy Hook bays, extends southwestward along the main railway lines through New Brunswick, Trenton, Philadelphia, Baltimore, and Washington;

(b) Its fall line features appear on the Delaware at Trenton, on the Schuylkill at Philadelphia, on the Potomac at the Great Falls above Washington, D. C., and on the James River at Richmond;

(c) Its cuesta forms the foundation of Long Island, the Atlantic Highlands, and the ragged front making up the hilly belt of southern New Jersey.

3. The Newark Lowland is a plain developed on inclined weak strata consisting of red sandstones and shales of Triassic age. The in-

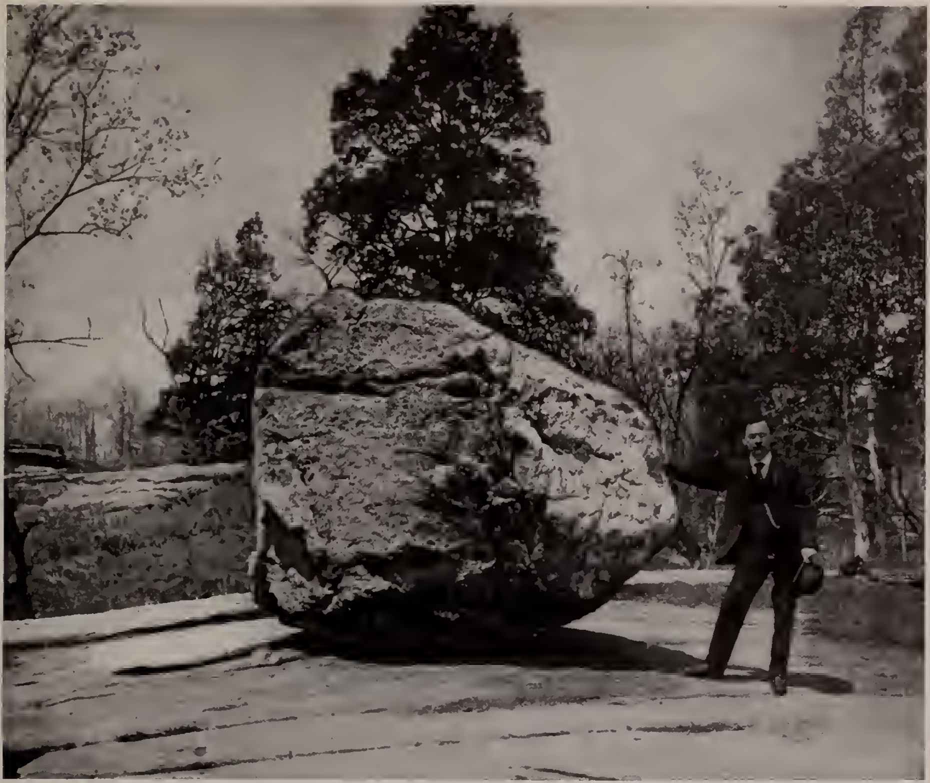


Sketch map of New York City and vicinity, showing position of the terminal moraine and directions of the ice movement (indicated by the arrows) during the last or Wisconsin glaciation. After United States Geological Survey.

trusive sheets of resistant volcanic rock form the prominent residual ridges known as the Palisades, Watchung, Hook, Cushetunk and Sourland mountains, and Long and Rocky hills.

4. The New England Upland is represented in the district by the Manhattan and Reading prongs. This upland consists of dissected and disordered crystalline rocks. The Manhattan prong extends down the east bank of the Hudson estuary from the Highlands to and including Manhattan Island. The north central portion of Staten Island is an outlier. The Reading prong extends as highlands from the gorge of the Hudson southwestward across New York and New Jersey to Reading, Pennsylvania.

5. The broad valley to the west occupied by the Wallkill and Paulins Kill is a part of the great Appalachian Valley, which extends from



The "rocking stone," New York Zoölogical Park, an ice-transported bowlder resting on a glaciated surface.

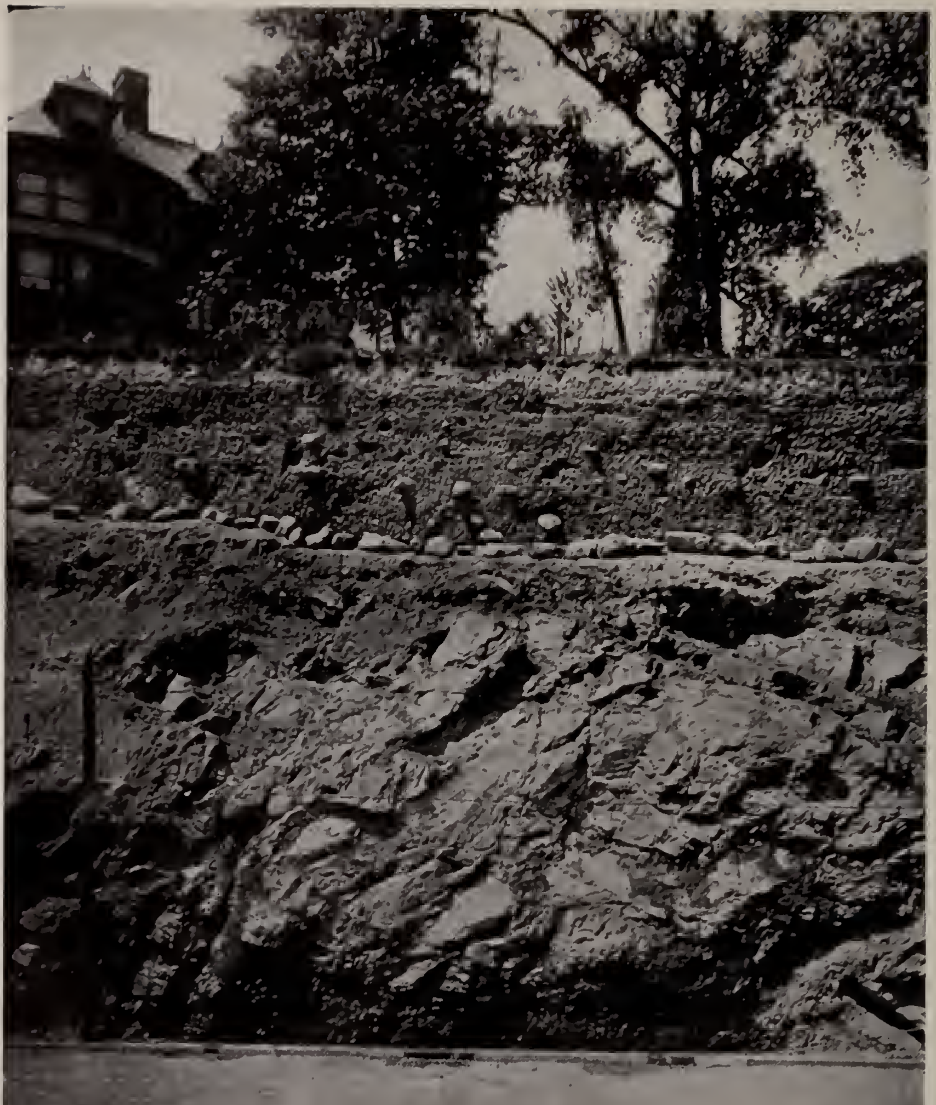
Birmingham, Alabama, to Lake Champlain. It is one of the prominent subdivisions of the Newer Appalachian physiographic province.

6. The narrow Kittatinny Mountain ridge dipping westward, represents the northeastern extension of the belt of newer and folded Appalachians of central Pennsylvania.

7. The Alleghany Plateau appears west of the Delaware River. Farther north in New York State the Catskill Mountains represent a subdivision of this plateau.

RELIEF MODIFIED BY GLACIATION

The northern portion of the New York City district has been traversed at least four times by great sheets of ice which moved down from the Labrador center. These continental glaciers modified the drainage and the surface of the land over which they passed. The terminal moraine which represents the southernmost extent of the last ice field



Exposure of glacial till, containing sand, gravel, and bowlders, in contact with Serpentine rock, at Castle Point, Hoboken. After United States Geological Survey, Passaic Folio, No. 157

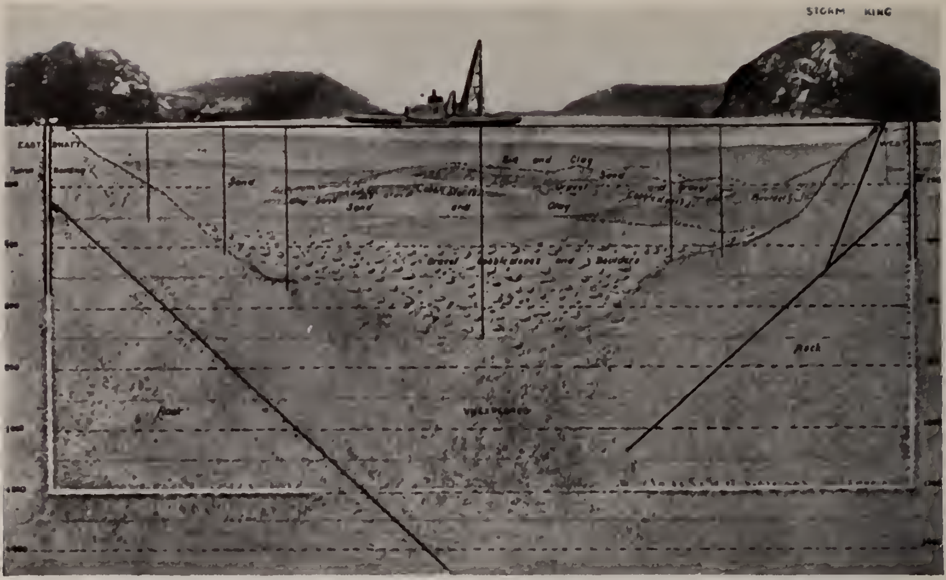
appears as a conspicuous ridge consisting of knobs and kettle holes on Long Island, Staten Island, and New Jersey. It continues westward across the United States to the Pacific Ocean near Seattle, Washington.

The drift bowlders and unsorted rock débris in the terminal moraine and northward give a clue as to the direction of ice movement. Large bowlders of crystalline rock from Jamaica and Hollis, Long Island, indicate that they were plucked out of the bed rock in the vicinity of Yonkers, Mt. Vernon, and other places in Westchester County, New York. Glacial-borne pebbles containing fossils and oolites have been found at Broadway and 191st Street. The fossils represent minute fragments of bryozoa and corals, of Devonian age, which are similar to those found at present in the Catskill Mountain region. The oolites, which are small, concentric spheres cemented together, resemble fish roe. They, too, came from up-state New York. On Staten Island, Long Island, and Short Hills, New Jersey, many large drift bowlders of sedimentary origin and containing numerous marine fossils were derived from the exposures in east central New York State.

Each of the four continental glaciers of the Pleistocene epoch consisted of ice thousands of feet thick. They not only plucked out huge bowlders the size of a house and transported them long distances, but they also scoured off the soil-cover in many places and left bare rock surfaces, *roches moutonnées,* little deserts in fact, on which no plants other than lichens can grow. A good example of a glaciated surface with an ice-transported bowlder resting upon it is the "rocking stone" in the New York Zoological Park, Bronx, figured above.

Rocks held firmly in the base of the ice served not only as abrasives but also as etching tools. Deep parallel grooves in crystalline rock appear at various places on Riverside Drive, particularly on the south side of the Drive where it leaves the Hudson River at about 200th Street. These glacial striæ running northwest-southeast give the direction of ice movement. Many diabase bowlders from the Palisades found in Yonkers and New York City indicate that the ice moved southeasterly, diagonally across the Palisades and the Hudson River, as shown on the diagram, page 4.

A stream leaving the front of the glacier oftentimes contained a large volume of water and had considerable transporting power. Hence pebbles, sand, and fine rock débris were carried in considerable quantity. In most instances the streams deployed fanwise almost immediately on their emergence from the glacial sheet and the material carried from the ice was dropped close to the margin of the glacier. The fans formed by single streams were usually small, being from half a mile to two miles in radius; confluent fans were larger, varying from one to six miles in

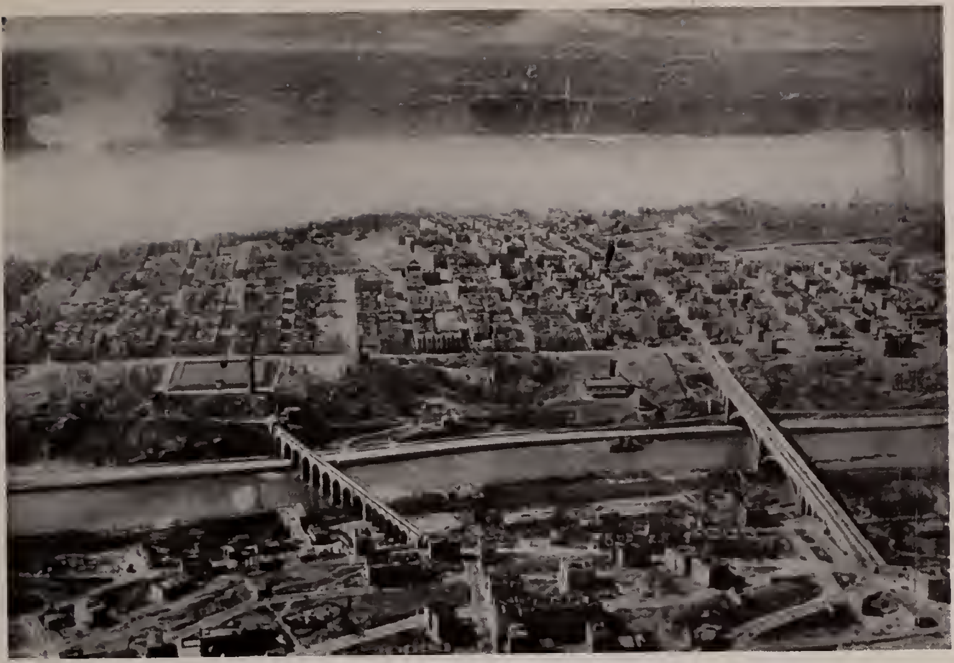


Cross-section drawing of the sediments in the Hudson River at Storm King Mountain, where is located the great siphon of the New York City aqueduct. From *Bulletin* 146 of the New York State Museum

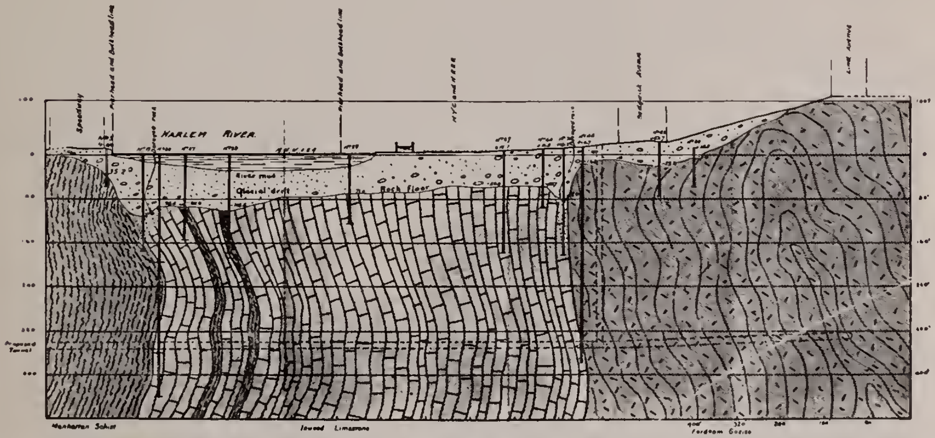
radius. The materials are somewhat sorted and stratified and are called outwash deposits. These deposits occur at short intervals along the southern margin of the terminal moraine. Towns built on some of the larger outwash plains are Plainfield, New Jersey, Flatbush and Hempstead, Long Island.

While glacial streams were depositing fan-shaped outwash deposits in many places along the ice front, a glacial lake, Lake Passaic, appeared to the south of the terminal moraine between the crescentic outline of the Watchung Mountains on the east and south and the New Jersey highlands on the west. The waters of the lake drained through the Muggy Hollow outlet at the southwest corner into the Raritan River valley. When the ice front retreated northward, the lake waters followed it and occupied the entire basin behind the Watchung Mountains to the west and southwest of Paterson, New Jersey. The numerous fresh-water marshes of today, along the upper course of the Passaic River, cover portions of the bed of this former glacial lake. See map, pages 14–15.

Great accumulations of glacial till, a mechanical mixture consisting of unsorted clay, sand, pebbles, and small bowlders, are found generally in the wake of the glacier. In the New York City district it varies from a fraction of a foot to 500 feet in thickness. A good exposure of it resting



Airplane view of Upper Manhattan Island, with the Harlem River in the foreground, the Hudson river and Palisades in the background. The three aqueducts, High Bridge, Croton and Catskill, which supply water to New York City, enter Manhattan at this point.



Cross-section of the Harlem River near High Bridge showing the sub-surface crossing of the Catskill aqueduct, the distorted rocks, and the fill of glacial drift and alluvium in the river bed. From *Bulletin* 146, New York State Museum.

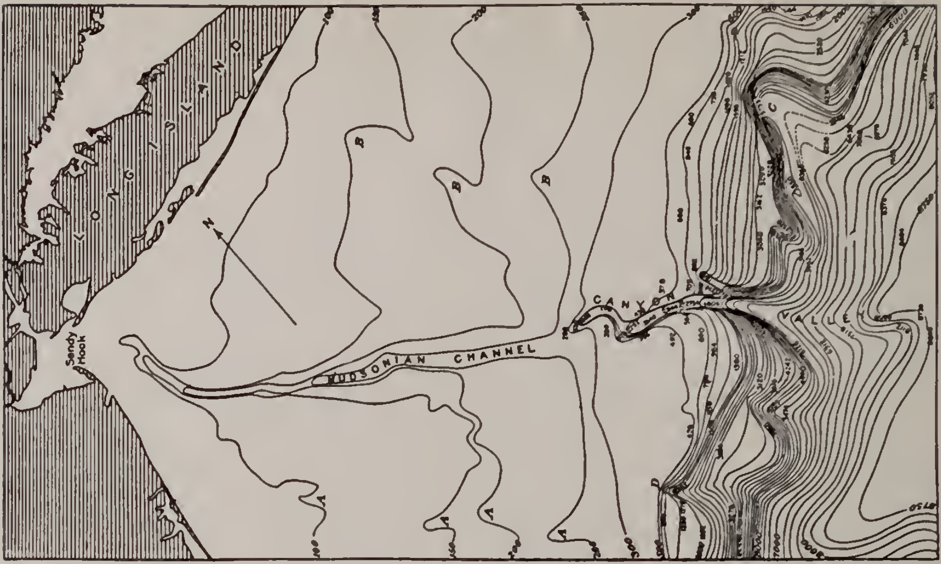


Chart of the outer submarine channel and canyon of the Hudson River. After United States Geological Survey.

on serpentine rock may be seen at Castle Point, Hoboken, New Jersey, page 6. It oftentimes fills the pre-glacial stream valleys and frequently covers the leeward side of hills and the lower areas. Test holes in the Harlem River at High Bridge show that the channel has been filled up from 80 to 111 feet by glacial drift and river mud, page 9.

The glacial drifts and sediments in the Hudson River gorge at Storm King Mountain have been found by drilling operations to be between 768 and 995 feet thick, with an average of 800 feet. In the vicinity of the Pennsylvania Railroad tunnels at 32d Street, New York City, the sediments are 300 feet thick, with a possible greater depth in an untested section in midstream. In the Lower Bay deposits accumulated to such an extent that the mouth of the river was almost closed to large ships. Some $4,000,000 have been spent by army engineers in dredging the Ambrose Channel 2000 feet wide by 40 feet deep, so that the large ocean liners and other vessels may enter the harbor. From a point ten miles out from Sandy Hook to the edge of the continental shelf about one hundred miles distant, a well-defined river channel exists which increases in depth seaward. Near the brink of the continental platform it is 4800 feet deep. Glacial deposits appear over a portion of the course, page 10.

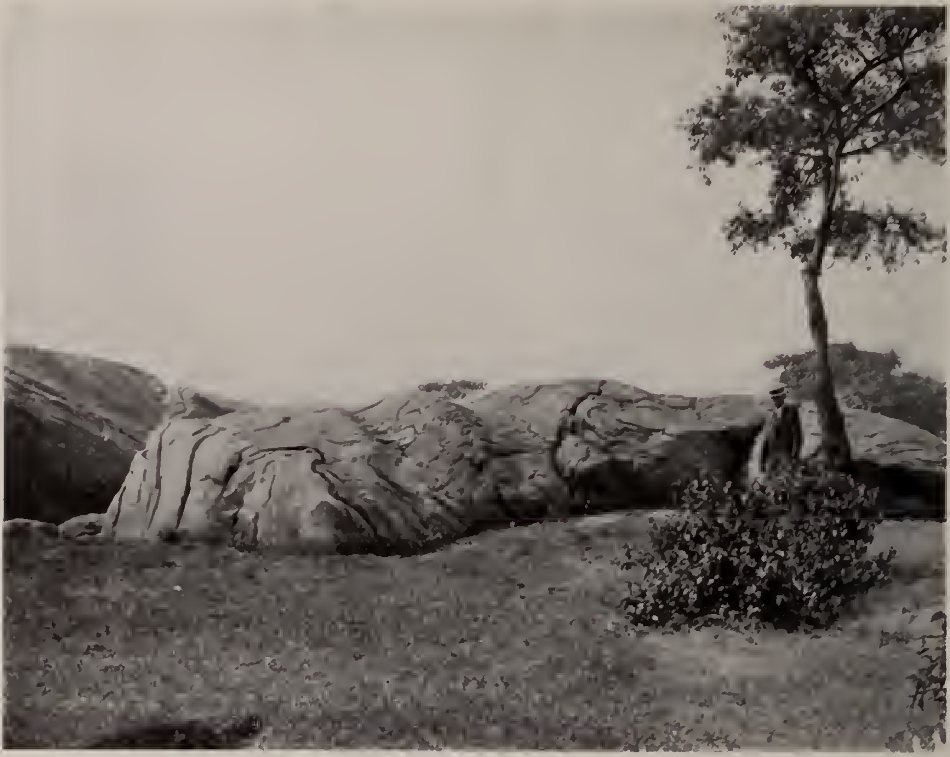
RECENT SHORE DEPOSITS

Sandy Hook, Coney Island, and Rockaway Beach are pronounced coastal irregularities. South Beach and Midland Beach, Staten Island, are less so. These features are temporary for they represent initial stages in the process of coastal simplification. After the initial reefs and barriers have become land, the lagoons behind them are likely to be filled with sediment and organic matter, forming land. See map, pages 14–15.

The development of curved spits and beaches along the New Jersey and Long Island shores is worthy of consideration. In the vicinity of Long Branch, New Jersey, the sea cliff indicates wave erosion. The eroded débris is shifted northward by the waves and currents and piled up along the beach which terminates in Sandy Hook. The tendency of the hook to turn westward is due largely to the strong westward sweep of the winds and tides of the Atlantic Ocean. This has been going on for some time, for Sandy Hook is a compound, recurved spit. Rockaway Beach is also compound in appearance, while Coney Island is simple. The same forces which shift the sediments north along the New Jersey shore are moving them westward along the Long Island coast in the vicinity of Rockaway and Coney Island. As Staten Island lies across the path of these waves, South Beach and Midland Beach represent a barrier or bar which has been built up by the waves near the line of breakers. That the prevailing direction of currents along the Midland Beach is to the southwest is indicated by the development of a spit in the vicinity of Great Kills. Beach deposition and straightening of the coast line is also in progress on the south shore of the Lower Bay in the vicinity of Port Monmouth, New Jersey.

The estuaries and lagoons east of Port Monmouth are being filled with sediments derived from the land and the growth of vegetation, for, being in the lee of Sandy Hook and the barrier beaches, they are protected from strong sea waves. This is also true of Jamaica Bay, the Flushing Creek basin, Hackensack Meadows, Newark Bay, and the upper reaches of Arthur Kill. These bays and estuaries are the result of recent subsidence of the area. Thus the drowned lands, which now represent shallow sea floors, have been a factor in the placing and development of certain pronounced hooks and barrier beaches. The wind has also notably modified the deposits made by the waves and currents, for it has developed long ridges and sand dunes on the surface of the beaches.

In addition to the shore deposits which are of recent development there are rocks exposed in the New York district which have greater age and a more profound history. There are at least five series of them. See geologic map page 15. While they are in close juxtaposition and



Ancient contorted Manhattan schist (Archæozoic) with rather recent glaciated surface (Pleistocene). See geologic map, pp. 14–15. South Meadow, Central Park, Manhattan. E. O. Hovey, photo.

have a well-established relation to each other, they are widely separated in origin by great intervals of time. Each series has had its normal period of development; the oldest, however, has suffered greater physical and chemical changes imposed upon it by mountain-making movements and other deformations which have affected it during the growth of the North American continent.

In passing from a consideration of the present shore developments to the oldest series of rocks exposed in the area, we go rapidly backward from the Age of Man through the Age of Mammals, the Age of Reptiles, the Age of Amphibians, the Age of Fishes, the Age of Invertebrates, to the little-known but inferred Age of Unicellular Organisms. We shall not consider the ever-changing shore line, the configuration of the lands and seas, and the great accumulation of sediments which have taken place slowly and repeatedly during these ages.

We shall have to omit a discussion of the birth, rise, decay, and disappearance of mountain ranges which have succeeded one another in this and other parts of the continent. Standing on the threshold of the better-known eras of geologic time, beginning with the Archæozoic, and turning our back on the hypothetical æons through which the earth must have already passed, let us approach the Present from the chronological point of view.

THE ARCHÆOZOIC ERA

In the dawn of life a series of limestones and associated sedimentary rocks were laid down in Canada near Ottawa, which have been called the Grenville series. According to Professor C. P. Berkey, of Columbia University, certain metamorphosed rocks in the Manhattan and Reading prongs of the New England upland are contemporaneous in age. The Fordham gneiss exposed in Bronx and Westchester counties and northward has all the physical characters of the Grenville series. It consists primarily of granitic and quartzose black and white banded gneisses and schists of very complex composition and structure. Interbedded quartzite and limestones and old igneous intrusions are also included. Note the position on the accompanying geologic map, pages 14–15.

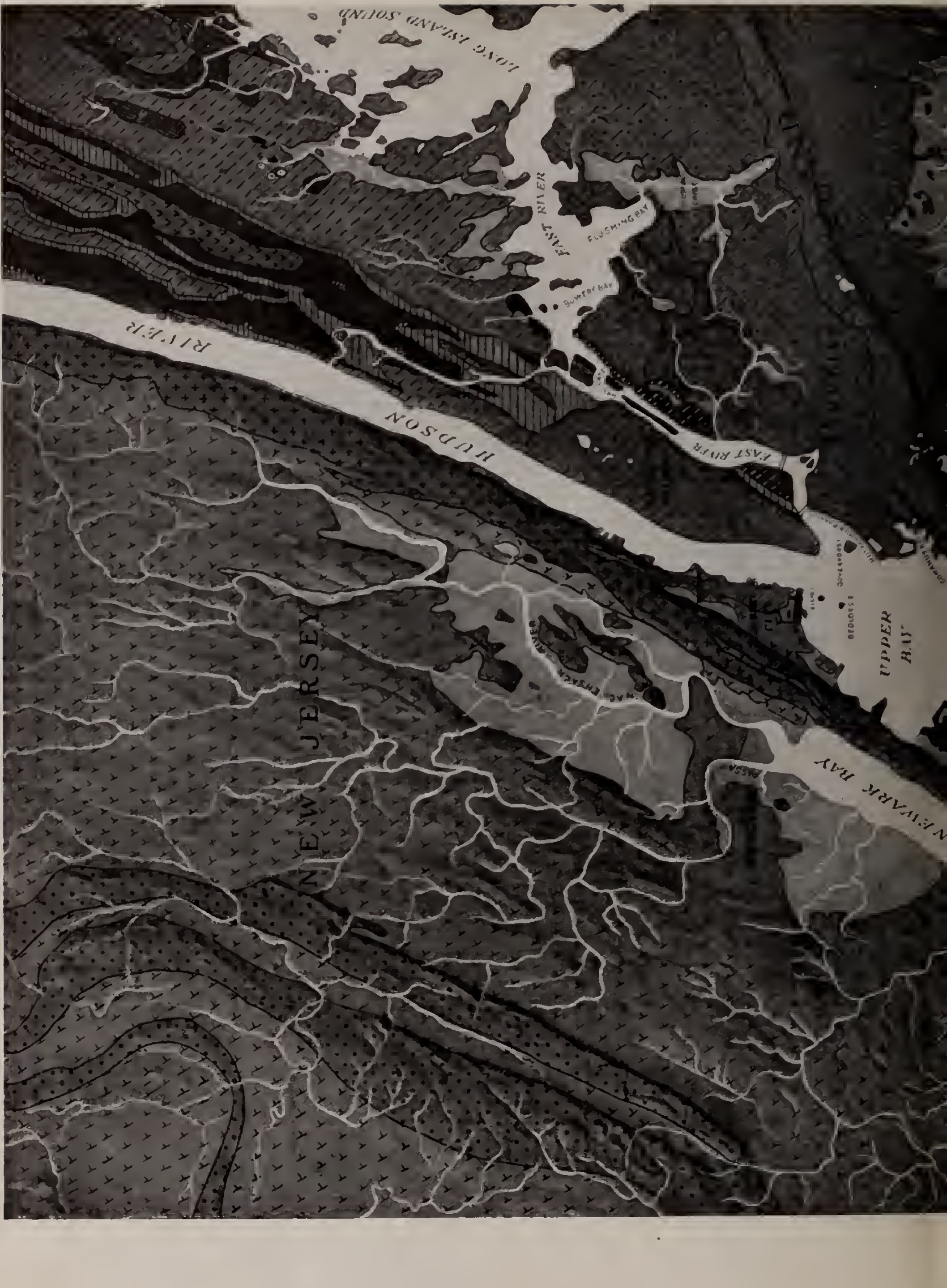
Resting upon the gneiss series in a conformable manner at Hastings-on-Hudson and other places is the Lowerre quartzite named after the locality in South Yonkers from which it was first described. It is a thin, schistose quartzite which varies in thickness from a fraction of a foot to 100 feet and rarely out-crops.

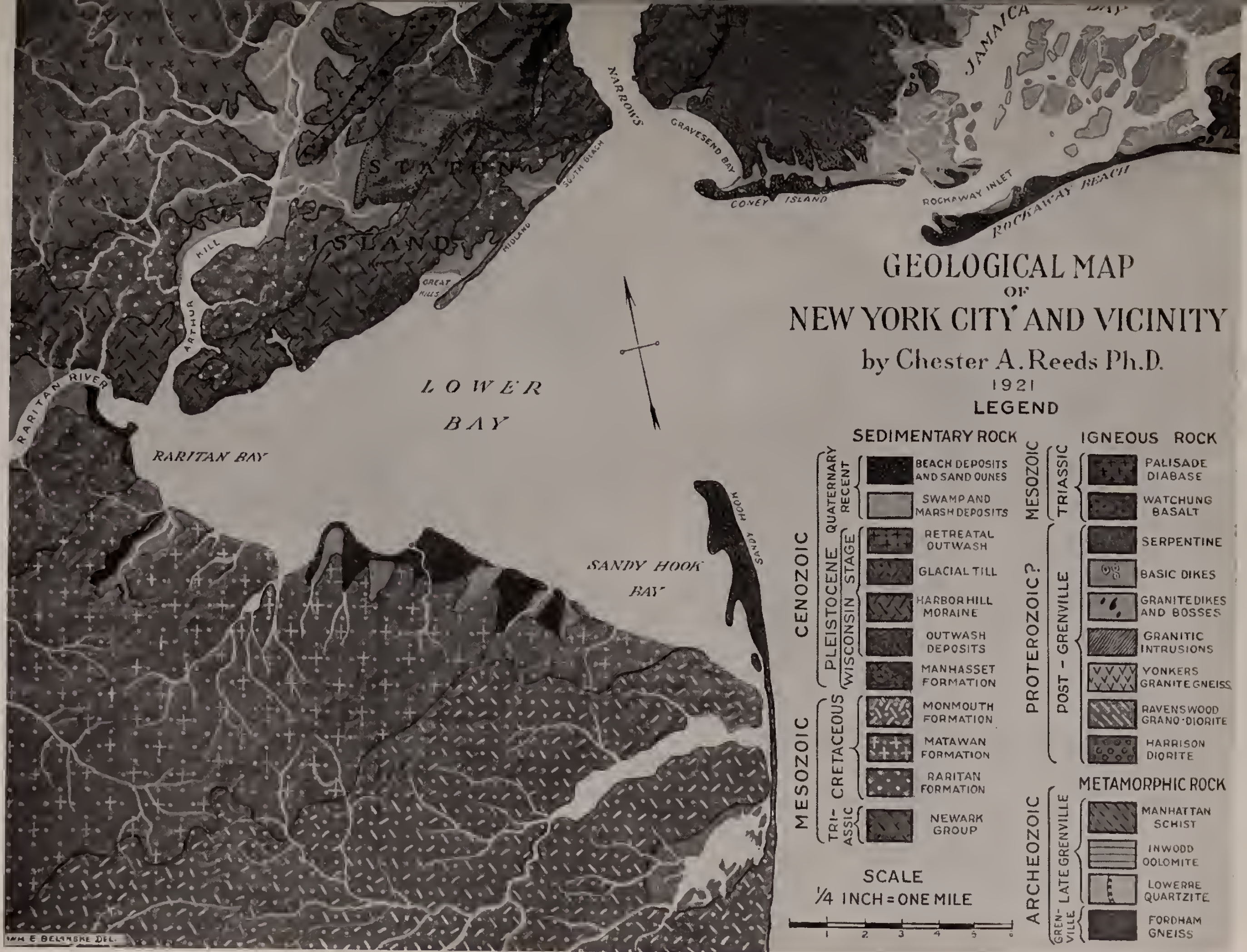
This formation is followed by a coarsely crystalline limestone locally tremolitic, micaceous, and pegmatitic, which varies in thickness from 200 to 800 feet. It is called the Inwood dolomite after the Inwood section of the city at the north end of Manhattan Island. Good exposures of the Inwood dolomite occur in the valley north of Dyckman Street, for instance at Marble Hill station on the New York Central Railroad.

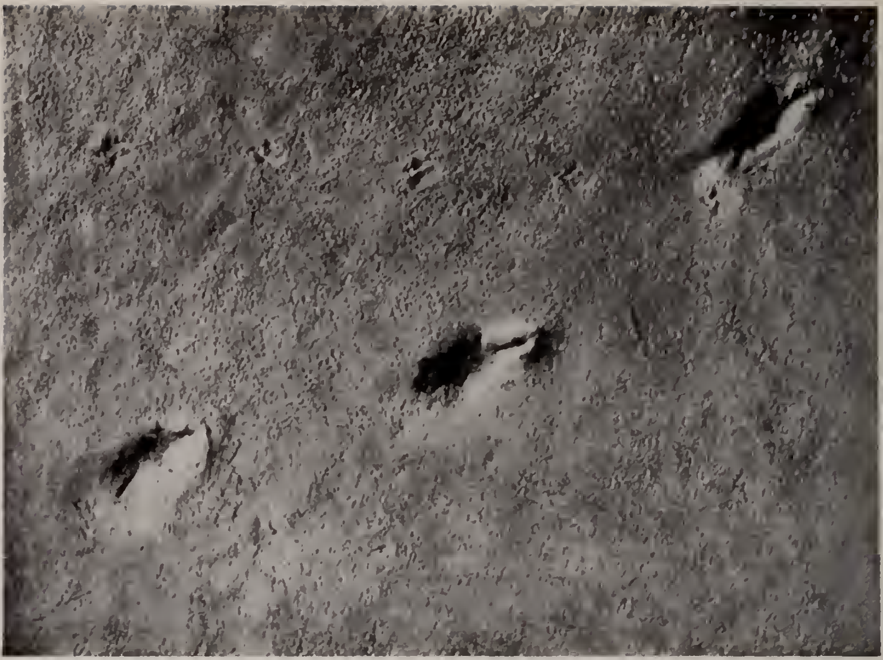
Conformably overlying the Inwood formation is a very thick, coarsely crystalline, pegmatitic mica schist, which is called the Manhattan, after the extensive exposures on Manhattan Island, page 14. The Lowerre-Inwood-Manhattan series is regarded as late Grenville in age. This and the Fordham series constitute the original sedimentary beds of the Archæozoic Era exposed in the New York City district.

THE PROTEROZOIC ERA, IGNEOUS ROCKS

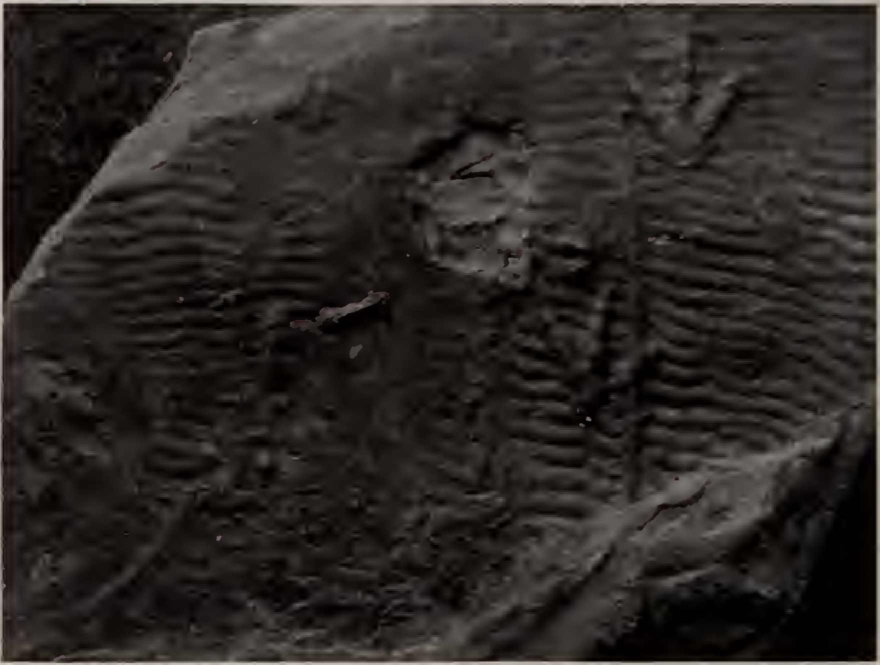
All igneous rocks of the crystalline area under consideration are younger than the sedimentary members into which they have been


LONG ISLAND SOUND
EAST RIVER
FLUSHING BAY
BOWERY BAY
HUDSON RIVER
EAST RIVER
NEW JERSEY
HACKENSACK RIVER
PASSAIC
UPPER BAY
NEWARK BAY

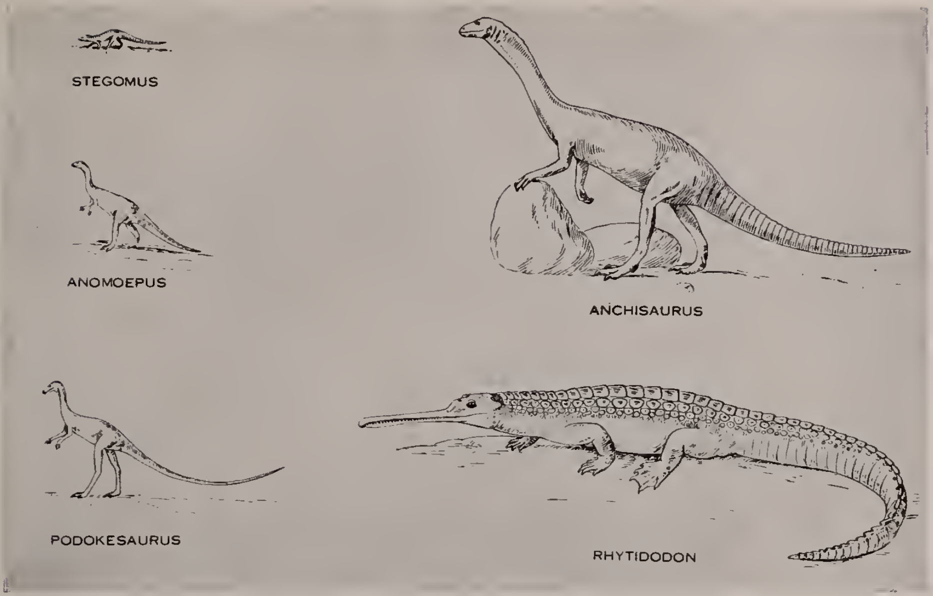

GEOLOGICAL MAP
OF
NEW YORK CITY AND VICINITY
by Chester A. Reeds Ph.D.
1921
LEGEND
SEDIMENTARY ROCK
CENOZOIC
QUATERNARY
PLEISTOCENE
RECENT
BEACH DEPOSITS AND SAND DUNES
SWAMP AND MARSH DEPOSITS
WISCONSIN STAGE
RETREATAL OUTWASH
GLACIAL TILL
HARBOR HILL MORAINE
OUTWASH DEPOSITS
MANHASSET FORMATION
MESOZOIC
CRETACEOUS
MONMOUTH FORMATION
MATAWAN FORMATION
RARITAN FORMATION
TRIASSIC
NEWARK GROUP
IGNEOUS ROCK
MESOZOIC
TRIASSIC
PALISADE DIABASE
WATCHUNG BASALT
PROTEROZOIC?
POST - GRENVILLE
SERPENTINE
BASIC DIKES
GRANITE DIKES AND BOSSES
GRANITIC INTRUSIONS
YONKERS GRANITE GNEISS
RAVENSWOOD GRANO-DIORITE
HARRISON DIORITE
METAMORPHIC ROCK
ARCHEOZOIC
LATE GRENVILLE
MANHATTAN SCHIST
INWOOD DOLOMITE
LOWERRE QUARTZITE
GRENVILLE
FORDHAM GNEISS
SCALE
1/4 INCH = ONE MILE
1
2
3
4
5
6
STATEN ISLAND
NARROWS
GRAVESEND BAY
CONEY ISLAND
JAMAICA BAY
ROCKAWAY INLET
ROCKAWAY BEACH
SOUTH BEACH
MIDLAND
GREAT KILLS
ARTHUR KILL
RARITAN RIVER
RARITAN BAY
LOWER BAY
SANDY HOOK BAY
SANDY HOOK
WM E BELANSKE DEL.



Slab showing passage of two Triassic dinosaurs after a shower. The rain-drop impressions are represented by small pits. After R. S. Lull.



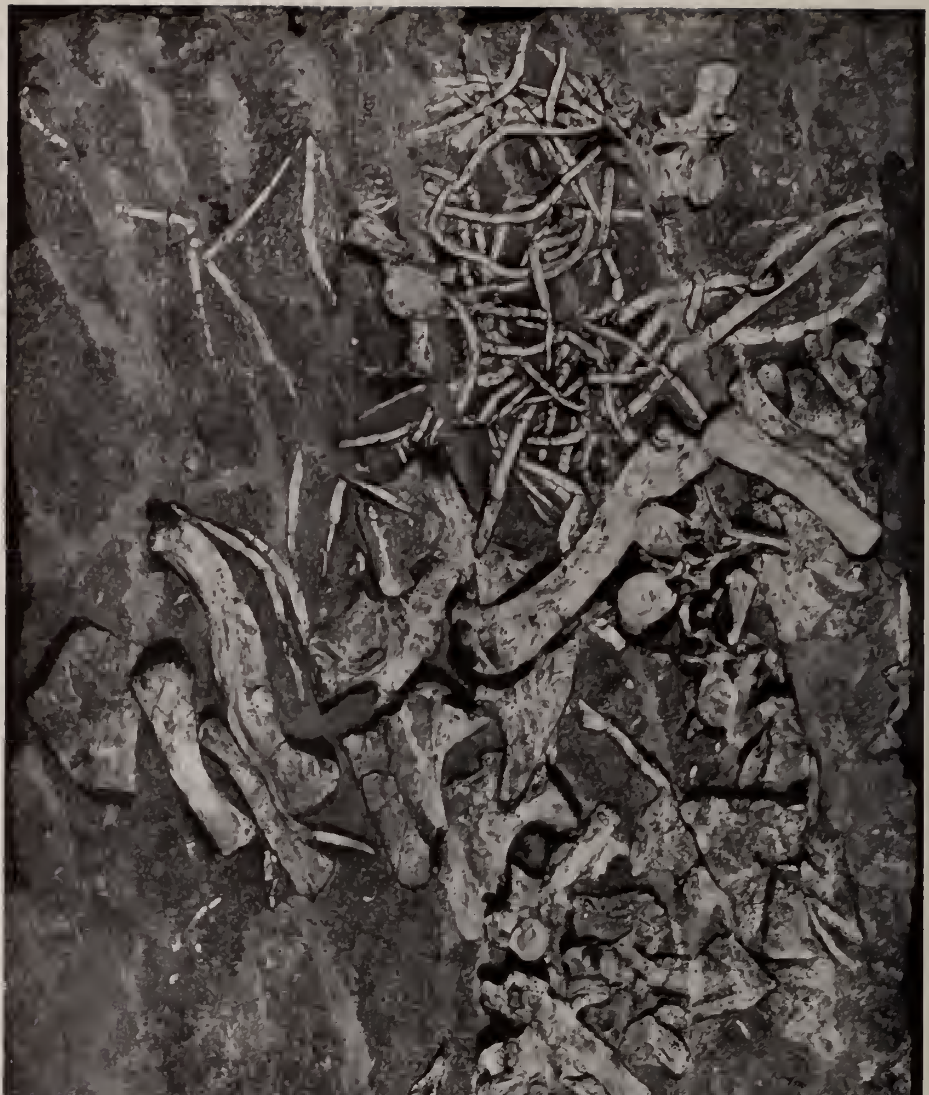
Impressions of the feet and tail of a Triassic dinosaur on a ripple-marked surface. Specimen from Pleasantdale, N. J.



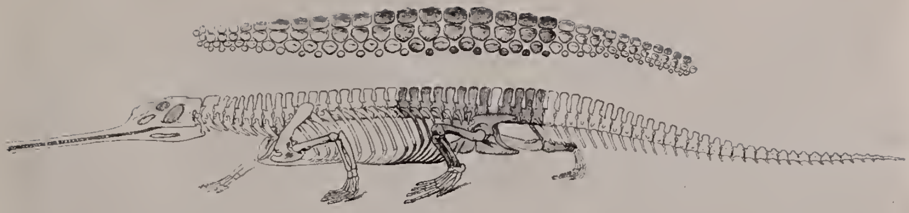
Certain types of dinosaurs of Triassic age which inhabited the New York, Virginia and Connecticut valley basins.

intruded. But they are not all of the same age or kind. There are granitic stringers and sills which may date back to the close of the earliest of these sedimentary periods, since they partake of all the metamorphic changes that characterize these ancient strata including recrystallization and flowage. The most striking examples are the Yonkers granite-gneiss, a sill, and the Ravenswood granodiorite, a boss. Some of the pegmatitic streaks and basic intrusions belong to a period of more extensive metamorphic activity and penetrate the Inwood dolomite and Manhattan schist. Examples are the Harrison diorite, basic dikes, granitic dikes, bosses, and intrusions as shown on the accompanying geologic map, pages 14–15. The serpentine which is found at Hoboken and over a large part of Staten Island is a metamorphic alteration product derived from similar basic intrusions.

The entire basal series of rocks have been folded, crumpled, faulted, crushed, injected, intruded, and intensely modified by recrystallization; nevertheless, they retain the fundamental association and essential character of an originally sedimentary series. Many of the gneisses, a few of the schists, all of the granites and diorites are of igneous origin and occur as sills, dikes, or bosses, cutting the metamorphosed sedimentary members. They, too, have been greatly metamorphosed and are very ancient, perhaps late Archæozoic or Proterozoic.



Fort Lee phytosaur, *Rutiodon manhattanensis*. Photograph of the skeleton as preserved in the original matrix. About 1/10 natural size. A description of it was published by the American Museum of Natural History, *Bulletin* XXXII, pp. 275–282, 1913



Restoration of the skeleton and dermal plates of *Rutiodon manhattanensis*. The shaded portion represents the parts preserved in the Fort Lee specimen. After W. D. Matthew.

Men excavating the skeleton of the Fort Lee phytosaur on the west bank of the Hudson River opposite 155th Street, New York City. The specimen was found in a red sandy marl about twenty feet below the thick sheet of diabase of the Palisades.

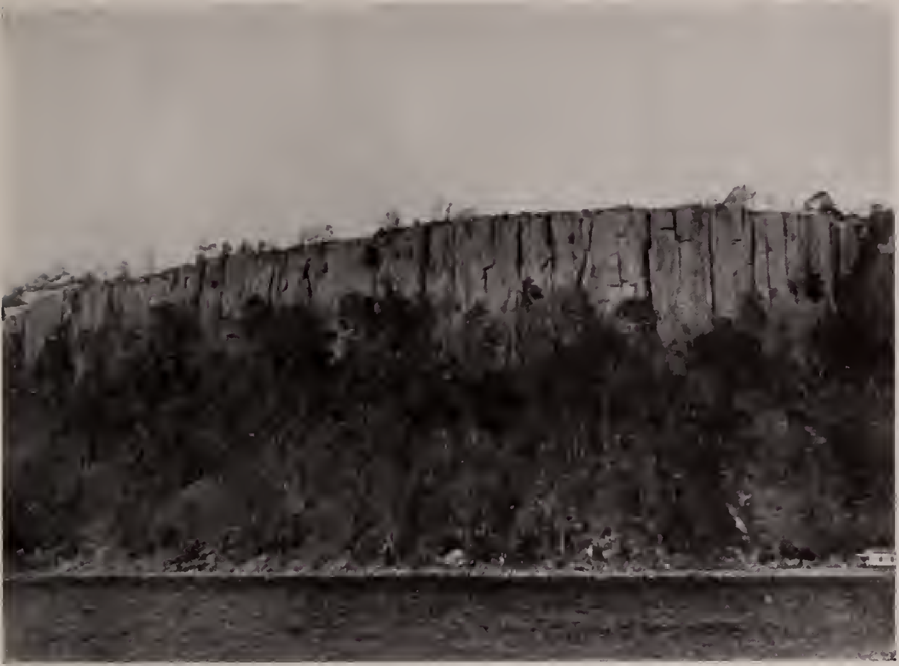
THE PALÆOZOIC ERA

The Palæozoic rocks and fossils, which represent a tremendously long period of time and follow the Proterozoic Era, are not found in the immediate vicinity of New York City except as glacial drift bowlders from up-state New York. They appear *in situ*, however, in great force in western New Jersey, New York, Pennsylvania, and the Mississippi valley states.

THE MESOZOIC ERA, TRIASSIC PEROID

From the Hudson River westward to the crystalline rocks of the New Jersey highlands occurs a thick series of reddish brown sandstones, shales, and congolmerates, called the Newark group, which dip 10 to 15 degrees to the northwest. Near Philadelphia, Trenton, and New Brunswick, the Stockton, Locatong, and Brunswick formations have been differentiated, but not beneath the glacial drift cover to the northeastward. These sedimentary rocks were deposited in a trough or graben with faulted margins which extended southwestward from the Hudson River across central New Jersey, Pennsylvania, and Maryland into southern Virginia. In all probability a major stream with lateral tributaries occupied the depression. The region was presumably high and arid. Ripple marks, mud cracks, rain drop impressions, and footprints of reptiles are common, especially in the Brunswick shale, and indicate flood plain and shallow water deposition. Restorations of the dinosaurs, *Stegomus*, *Anomœpus*, *Podokesaurus*, *Anchisaurus*, and *Rutiodon* (*Rhytidodon*), which inhabited this zone and the Connecticut Valley, are shown in accompanying illustrations pages 16–17–18. Only one skeleton, the Fort Lee *Rutiodon*, pages 18–19, has been found near New York City. Fossil fishes and a small crustacean, *Estheria ovata*, have also been found. The fossil remains indicate Triassic age, the initial period of the Mesozoic Era, sometimes called the Age of Reptiles.

Three successive lava flows which were extruded during the deposition of the Newark beds have been subsequently faulted, flexed, and tilted into their present position. Since that event erosion has removed a great thickness of sedimentary rocks and the upturned edges of the lava sheets are now exposed. The First and Second Watchung Mountains and Hook Mountain represent these three basaltic flows. The lowest, First Mountain, is about 600 feet thick; Second Mountain 800 feet, and Hook Mountain 300 feet. About 600 feet of red sandstone and shale separate the first and second, and 1500 feet the second and third. Red Triassic sandstone and shale are also found above and below these volcanic rocks.



Palisades of the Hudson opposite Spuyten Duyvil, N. Y.

The Palisade diabase is a great sheet of igneous rock, from 350 to 1000 feet thick, which was intruded among the lower strata of the Newark group. It extends from Staten Island northward along the west bank of the Hudson River to Haverstraw. At its southern exposed extremity it is practically at sea level, while at the north it is 700 feet higher. Throughout most of its extent it presents an escarpment of high cliffs with vertical columns of rock which were developed during the cooling stage and which suggest the name Palisades, page 19.

CRETACEOUS PEROID

Stratified rocks which represent the closing stage of the Age of Reptiles rest unconformably upon the Newark group in New Jersey and upon the crystalline basal complex in Staten Island and Long Island. Except for a few exposures along the north coast and the interior of Long Island, the Cretaceous sediments are hidden by glacial deposits of Pleistocene age. Their presence, however, is ascertained from numerous deep-well records. In the unglaciated area south of Raritan Bay, they are exposed over extensive areas. Here three well-defined members appear, the basal Raritan formation of plastic clays, the Mattawan formation of clay marls, and the Monmouth, including the Rancocas and Mansquan formations of green sand and marls. Fossil marine invertebrates and plant remains indicating Upper Cretaceous age are found in some of these beds. The Cretaceous deposits of Long Island, which average 1550 feet in thickness, vary greatly in composition within short distances and are, on the whole, more sandy than those of New Jersey. An exposure may be seen at Elm Point on Great Neck, Long Island.

The inclination to the southeast of the bed rock surface on which these sediments were deposited is about 40 feet to the mile in New Jersey, 80 feet near Oyster Bay and Huntington, and 40 feet at Port Jefferson, Long Island. The dip of the beds, which is the same as the slope of the unexposed floor, probably decreases toward the east and south. This old Cretaceous floor is still preserved inland in the crests of the Palisade and Watchung ridges, Schooley Mountain and Kittatinny Mountain of New Jersey and in the truncated folds of the Appalachian Mountains west of Harrisburg, Pennsylvania. Locally in Long Island the weak upper beds of the Cretaceous series have been greatly folded and contorted by the passage of the Pleistocene glaciers over them.

THE CENOZOIC ERA, PLEISTOCENE EVENTS

Four glacial and three interglacial stages are represented on Long Island. The periods of glaciation correspond to the Nebraskan, Kansan, Illinoian, and Wisconsin of the Central United States, and to the Günz, Mindel, Riss, and Würm of the Alps Mountains. Locally they have been named by Mr. M. L. Fuller, of the United States Geological Survey, the Mannetto, Jameco, Manhasset, and Wisconsin stages and are represented primarily by gravel and morainal deposits. The only ones represented within the limits of the accompanying geological map are the Manhasset and Wisconsin. The outwash, terminal moraine, till, and retreatal outwash deposits of the Wisconsin stage are far more extensive and more readily examined than the similar accumulations of the older stages since they were the last and cover in large part those made during the preceding glaciations.

The First Interglacial stage, the post-Mannetto, was long, for a great erosional unconformity exists. Following the deposition of the Mannetto gravel of the First Glaciation, there was a period of uplift and erosion in which the Mannetto was cut to a depth of 300 feet below sea level, as shown by the depth of the buried Jameco channel in Long Island. The great length of this period of erosion, indicated by the almost complete removal of the thick Mannetto gravel from the Long Island region, is in harmony with the time required for the cutting of the

Hudson River rock gorge to a depth of 750 feet below present sea level. The gorge proper appears to be filled solely with Pleistocene materials as indicated by the Storm King and other borings; hence, its cutting is to be referred to a date later than the deposition of the latest Tertiary beds in New Jersey.

The narrow, steep-sided and deep outer cañon of the submarine channel, page 10, if due to stream erosion, must be referred to an elevation of great magnitude, 4800 feet, occurring at the close of the post-Mannetto erosion stage. The great drops or falls in its beds are characteristic of a juvenile stream or an old one which has been rejuvenated. As only the edge of the continental shelf was notched, the epoch of maximum elevation must have been brief.

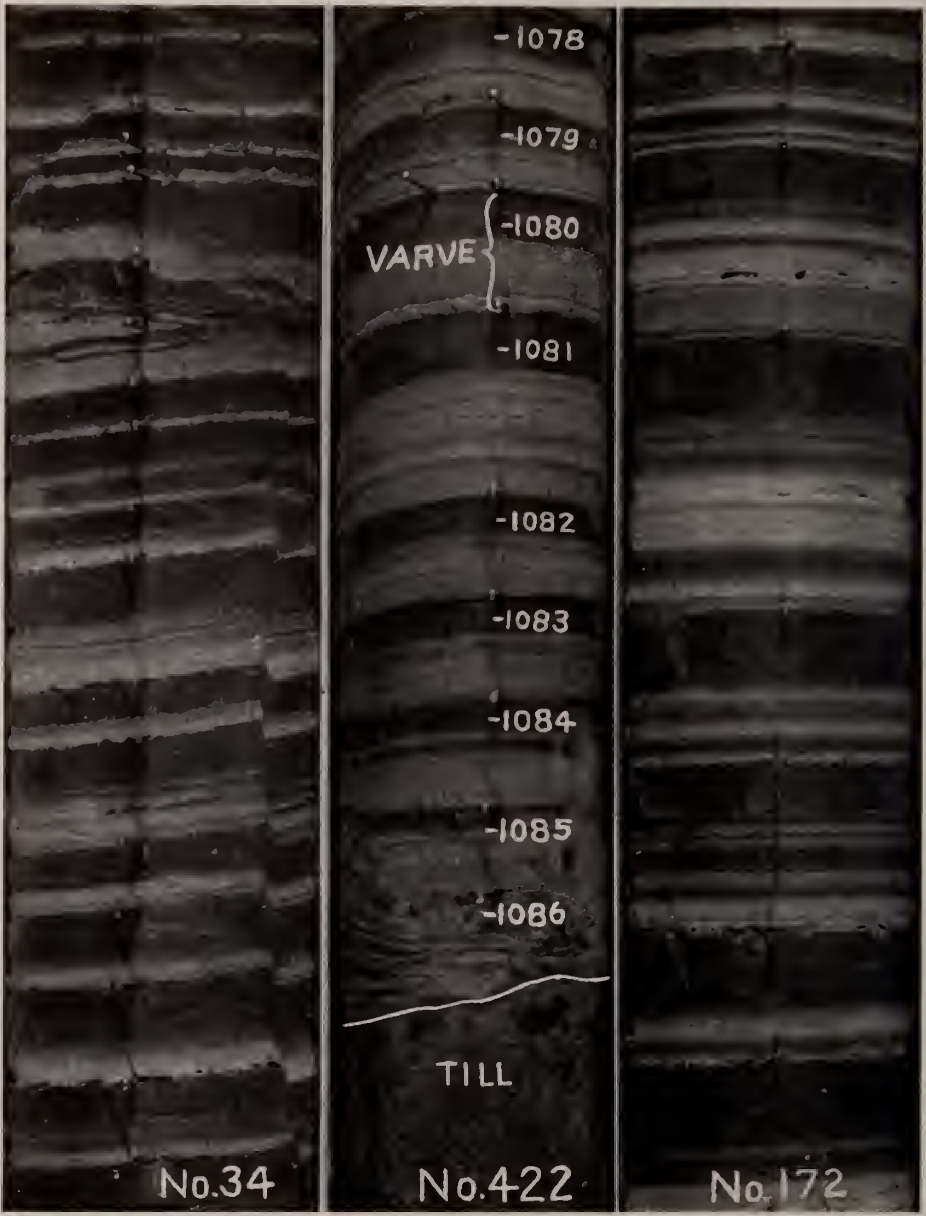
During the Second Interglacial stage, the Yarmouth of the Mississippi Valley, the Gardiner's clay was deposited in Long Island. It was followed by a transitional epoch represented by the Jacob sand. Throughout the time of the Second Glaciation, the Second Interglacial stage and the Third Glaciation, the channel of the Hudson remained constantly below sea level. The deposits, which have a combined thickness of about 500 feet, doubtless obliterated the upper reaches of the submarine Hudson channel.

The Third Interglacial interval, the Vineyard, is represented by (a) a great erosional unconformity, and (b) the Vineyard formation, consisting of marine deposits and peat. The valleys in the Manhasset deposits, although somewhat modified and partly filled with the later Wisconsin accumulations, are known to extend some distance below sea level at many points along the north shore, indicating a former higher position of the land. The present upper submarine channel of the Hudson, which has a depth at its outer end of 350 feet, suggests that the land must have been elevated to that extent during the Vineyard interval.

There are no erosion channels referable to Wisconsin or post-Wisconsin elevation on Long Island. The upper end of the Hudson channel, however, between Sandy Hook and Rockaway Beach, has been obliterated in part by Wisconsin outwash and in part by the shifting of the sands by the littoral currents that now sweep along the coast.

ADVANCE AND RETREAT OF THE ICE OF THE LAST GLACIATION

An examination of the maps pages 4, 25, will show that the southernmost point reached by the ice of the last glaciation was Prince's Bay, Staten Island, and Perth Amboy, New Jersey. The terminal moraine, which indicates the southern limit of glaciation, is not only well-developed at Perth Amboy, but it extends northeastward across Staten Island and Long Island, and northwestward through Summit and Morristown,



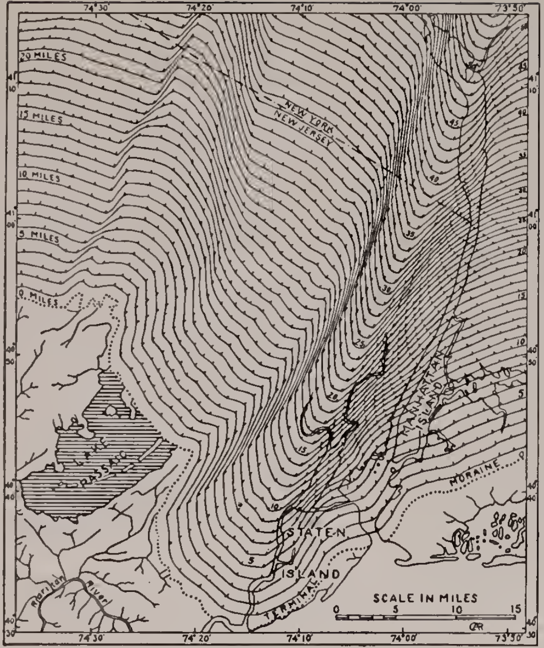
VARVED CLAY FROM THREE GLACIAL LAKE BEDS NEAR NEW YORK CITY

The thick dark bands denote the winter accumulation; the intervening lighter colored layers represent the summer deposition. A pin at the upper edge of each of the dark winter bands marks the limits of each varve. The distance between pins thus represents a varve, or annual deposit.

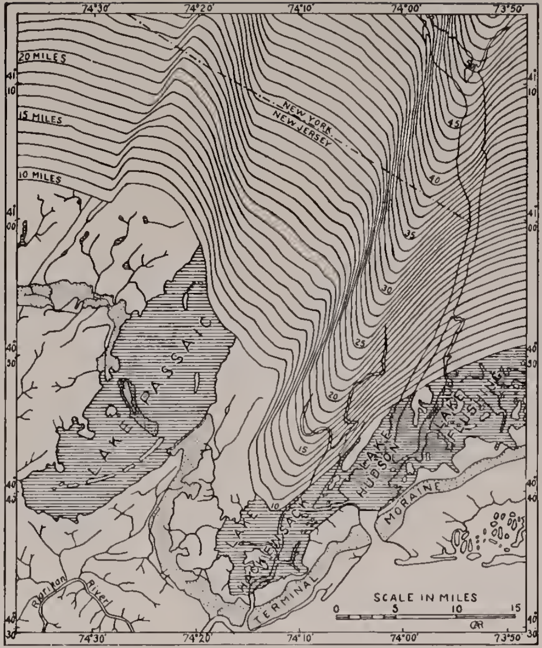
Section No. 34 contains eighteen varves deposited in glacial Lake Passaic one half mile north of Mountain View, New Jersey. An offset in the layers near the right margin represents a fault: the joining of two dark winter bands in the upper right of the section is due to a lateral slide.

Section No. 422 is a bottom sample taken from clay deposited in Lake Hackensack, one mile north of Little Ferry, New Jersey. The bottom varve (−1086), which rests upon the glacial drift or till, has been disturbed by a slide. The numbers with negative sign represent the author's count of the varves below a datum plane for the Little Ferry district, described in *American Museum Novitates* No. 209, 1926. This section was cut by a special clay sampling tool, at a depth of ten feet, below the lowest working level of the Gardiner clay pit.

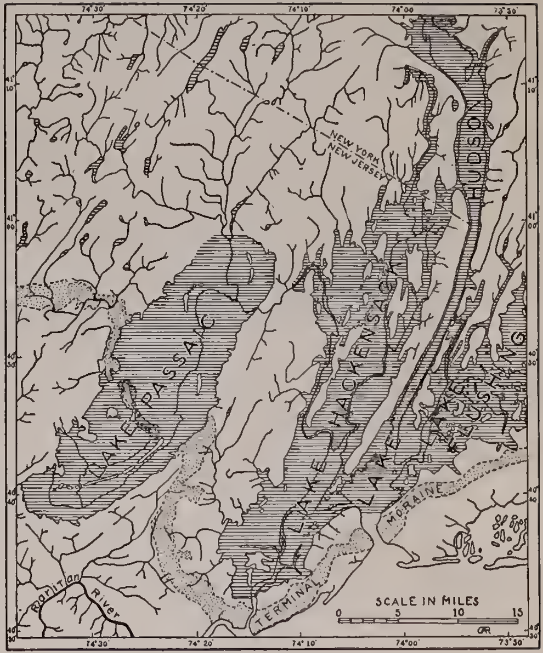
Section No. 172 from the Archer pit, Haverstraw, New York, shows nine varves deposited in Lake Hudson. The varves in this sample are thicker than those in the other two samples. Sections No. 34 and No. 172 are gray in tone, while No. 422 is of a pronounced red color. The color of the clays is ascribed to the difference in the color of the underlying rocks, which were scored and scoured by the advancing glacier.



Sketch map showing maximum extent of the ice of the last glaciation in the vicinity of New York City; direction of ice advance (dotted radial lines); probable waves of advance and retreat of the ice, measured in mile stages from the terminal moraine; outline of extra-morainal Lake Passaic



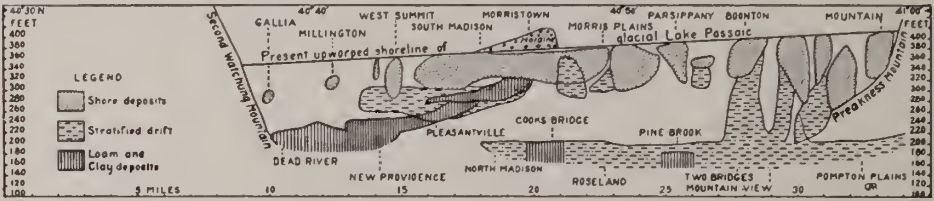
Sketch map of the probable position of the ice-front in the vicinity of New York City after having retreated ten miles from the outer margin of the terminal moraine; Lake Passaic well developed; early stage of Lakes Hackensack, Hudson, and Flushing



Sketch map of maximum extent of glacial lakes Passaic, Hackensack, Flushing, and Hudson in the vicinity of New York City, shortly after the retreat of the ice of the last glaciation. The terminal moraine, present drainage, and smaller glacial lakes are also noted.

New Jersey. The front of the glacier thus assumed a sinuous lobate outline due no doubt to the rather broad open features of the Hackensack valley, throughout the fifty miles of its north-south extent, as compared with the narrow and deep defile of the Hudson River, the major stream, to the east. The Palisades ridge along the east flank of the Hackensack valley, and the Watchung Mountains and New Jersey Highlands along the northwest margin, tended to retard the glacier as it moved southward in those areas. The directions of ice movement, derived from the glacial scratches or striæ, are indicated on the maps, pages 4, 25, by the dotted radial lines. The Hackensack valley thus became the main line of advance of the glacier, and being lower in elevation than the adjacent areas, it contained the greatest thickness of ice.

At the present time no one knows how long the ice-front stood at the terminal moraine; we can merely guess and say several thousand years.



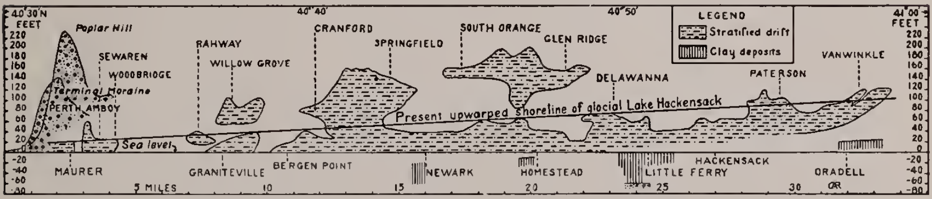
Profile drawing showing upwarped shore-line and vertical distribution of the stratified deposits in glacial Lake Passaic. Data from glacial geology sheets of the Passaic and Raritan Folios, U. S. Geological Survey.

Neither does anyone know definitely where the ice-front stood during the successive stages of the annual retreat northward. We can assume, however, as a working hypothesis, that it retreated equally along the entire sinuous front. On the map page 25 the assumed stages, at intervals of one mile, have been indicated, following in reverse direction the same radial lines (dotted) along which the ice is known to have advanced. According to this theory the ice-front at any one position, for example, the ten mile stage page 25, was very irregular, with the ice-tongue in the Hackensack valley persisting after the adjacent highlands had been cleared of ice.

GLACIAL LAKE PASSAIC

When the ice-front reached its maximum extent, a glacial lake known as Lake Passaic partially filled the natural basin to the south of the terminal moraine, in the vicinity of Summit and Morristown, New Jersey. Its southern shore followed the recurved basaltic rock of the second Watchung Mountain at an elevation of 345 feet, map, page 25. The lake waters did not rise above this height, for the Moggy Hollow outlet at the southwest corner permitted the water to flow out into a tributary of the Raritan River and eventually into the sea.

As the glacier retreated northward down the valley of the upper Passaic River, the waters of Lake Passaic followed the ice-front as far as Pompton Plains, pages 25, 26, and filled the entire basin lying between the Watchung Mountains and the New Jersey Highlands up to an elevation of 360 feet above sea level. The present lowest point in the lake basin is 160 feet above mean tide, so that the lake during its maximum extent must have had a depth of 200 feet. In some places the shore-line of this glacial lake is faintly preserved; in others it is well-developed, and must have existed for a considerable period. For a detailed mapping of the shore-line and deposits of this well-known glacial lake, one should examine the Passaic and Raritan Folios of the United States Geological Survey, and Volume V of the New Jersey Geological Survey.



Profile drawing showing upwarped shore-line and vertical distribution of the stratified deposits in glacial Lake Hackensack. Data from the glacial geology sheet of the Passaic Folio, U. S. Geological Survey, and the author's field notes.

VARVED CLAYS

As the glacier retreated from year to year, varved clays, page 24 were deposited in certain areas on the floor of the lake, particularly in low places near where the subglacial streams debouched. The basin has not been fully prospected for glacial clays, but the writer in 1922 observed a few varves close to the terminal moraine in Morristown, and in a clay pit at Whippany. Some 222 varves, many of which were contorted, were also examined in clay pits one-half mile north of Mountain View, and one and one-half miles northwest of Little Falls, New Jersey. In 1927, a partial section of the clay deposits in Lake Passaic, to the south of the Terminal Moraine, revealed numerous varves, many of which were contorted.

These lake clays are unique in that they are bilaminar for each year. (See illustration on page 24.) One layer represents the amount of "summer" deposition, the other the "winter" accumulation. Taken together, the paired bands constitute a varve or annual deposit.

The clays are of glacial age, since each layer had its origin in an annual retreat stage of the ice of the last glaciation. They were developed as follows: As the ice melted and retreated slowly northward during the warm summer months of each year, the swollen rivers which flowed out from under the ice mass picked up the fine sand and clay particles and transported them to fresh-water lakes which occupied the lower portions of the enclosed basins in front of the glacier. As the stream currents on entering the still waters of the lake gradually lost their power to transport their load of sediment, the fine sand and coarse clay particles settled down over the lake bottom to form the sandy summer layer. During the cold winter months of each year the ice-front became stationary, the englacial and subglacial stream courses either ran dry or congealed, and little, if any, sediments were transported by the rivers into the lakes. The surface of the lake also became encrusted with ice and snow, and the fine clay particles, which had been held in suspension in the milky water following the summer incursions, slowly settled to the bottom to form the bluish, reddish, or dark winter layers composed of pure clay. Before the end of the winter season, the lake waters cleared, and a sharp line of demarcation was established between the top of the "winter" layer and the base of the succeeding "summer" layer. This well-defined line is of value to the collector or student in separating the seasonal layers into varves or annual deposits.

UPWARPED SHORE-LINES OF LAKE PASSAIC

Since the glacier disappeared from eastern North America, the shore-lines of former glacial Lake Passaic have been warped upward 67 feet (412 feet less 345 feet) more at their northern end than along their southern margin. The lake had an extent of 30 miles along its northeast-southwest axis, or 26 miles on the meridian. This represents a differential upwarping of the region in the vicinity of New York City, in a north-south direction, of approximately 2¼ feet per mile, or twenty feet in nine miles. This marked change in elevations of the land is known to have affected all the territory occupied by the continental glacier in central and eastern North America, extending from a zero or hinge line in central New Jersey up to approximately 1000 feet to the north of Quebec, Canada. Such differential changes in elevation are not confined to eastern North America, for it has been noted that the glaciated territory of northwestern Europe has been upwarped in a similar manner. Where the relief of the land was affected most, it is believed that the ice was thickest. It was the removal of the load of ice and certain subcrustal or isostatic movements that took place within the earth, that in all probability brought about the changes in elevation.

GLACIAL LAKE HACKENSACK

Prior to 1922, when the writer began his investigation on the clays of the Hackensack basin, glacial Lake Hackensack had not been outlined or recognized. The commercial value of the clays, however, had been noted by various state and federal geologists. Twenty to thirty years ago brick yards were established at various points in the northern half of the Hackensack valley but at present all these enterprises have been discontinued except in the vicinity of Little Ferry, where large open pits have been excavated below sea level. To the south of this point the basin is for the most part covered by salt water or salt-water marshes.

The varved clays, however, were deposited in a fresh-water glacial lake and not in an arm of the sea.[1] While the shore-lines of this glacial lake have not been traced in detail in the field, we know the amount of post-glacial upwarping for the Lake Passaic basin, and can apply that data with profit to the Hackensack valley.

Glacial Lake Hackensack, as shown on the sketch map, page 125, was outlined by the writer in 1924, and presented in abstract the same year at the Ithaca meeting of the Geological Society of America.[2] The approximate shore-line starts with the Maurer delta deposit which rises from sea level to 30 feet, inside the terminal moraine less than two miles north of Perth Amboy. With this delta as a bench mark, the 20, 40, 60, 80, 100, and 120 feet contour lines on the topographic maps were followed for nine miles each, the last one of which encompasses the northern end of the Hackensack valley. The reason for changing contours every nine miles is that the amount of postglacial uplift of the ground averages two and one quarter feet per mile, or twenty feet in nine miles. Lake Hackensack as thus outlined contains not only a number of ridges as islands, but also the glacial clays and the stratified sands, gravels, and delta deposits which rise to successively higher and higher elevations in passing from south to north.

The glacial clays which occupy only the lowest levels are reported in deep wells in south Newark; at Homestead the top of the clay is 10 feet below sea level; at Little Ferry approximately at sea level; at Oradell about 15 feet above; at Norwood 30 feet above; and at West Nyack 50 feet above tide.

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[1] Antevs, Ernst, 1925, "Condition of Formation of the Varved Glacial Clay," *Bull. Geol. Soc. Amer.*, Vol. 36, pp. 171–172.

[2] Reeds, Chester A., 1925, "Glacial Lake Hackensack and Adjacent Lakes," *Bull. Geol. Soc. Amer.*, Vol. 36, p. 155.

The delta deposits and stratified sands and gravels, which occur at such discordant elevations that heretofore they have baffled explanation, also rise to higher and higher levels in going northward. For example, the delta deposits in North Hackensack occur at an elevation of 40 to 50 feet above sea level, while farther to the north the sandy delta plains in the vicinity of Tappan rise from 60 to 80 feet above sea level. To note the vertical relations of the various stratified deposits, as mapped on the glacial sheet of the Passaic Folio, to the newly outlined shore-line of Lake Hackensack, and the relation of similar deposits in Lake Passaic, see the cross-section diagrams on pages 26, 27. It is surprising how well these varied deposits fall in below the shore-lines in both lakes. The exceptions in the Hackensack valley are the deposits at Willow Grove, Cranford to Springfield and South Orange to Glen Ridge, which occur at higher elevations, and which were in all probability deposited not in Lake Hackensack, but in small lakes which lay at higher elevations hemmed in by early retreat stages of the icefront and the back slopes of the terminal moraine and of the Watchung Mountains.

Varved clay of Lake Hudson smoothed for sectioning. Washburn and Fowler clay pit, West Haverstraw, New York.

In 1926 a composite section from five clay pits at Little Ferry, New Jersey, yielded a continuous series of 2550 varves, representing as many years for the deposition of the clay. One varve was laid down each year as the ice-front of the last continental glacier retreated northward up the Hackensack valley.[1]

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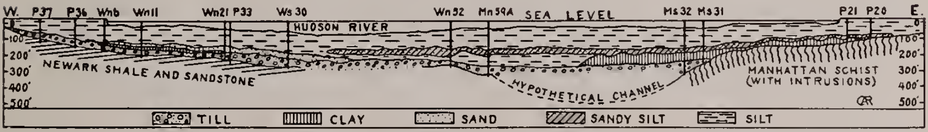
[1] Reeds, Chester A., 1926, "The Varved Clays at Little Ferry, New Jersey." American Museum *Novitates*, No. 209, pp. 1–16.

GLACIAL LAKES HUDSON AND FLUSHING

The same bench mark and methods of induction and deduction that were used in establishing the outline of Lake Hackensack were applied to the territory immediately to the eastward of the Hackensack basin and northward of the terminal moraine. The results of this endeavor, as noted on page 25, give us the suggestive outlines of variously connected bodies of fresh water which we have designated as Lake Hudson and Lake Flushing. Varved glacial clays are not known to be exposed above sea-level in Lake Hudson south of Haverstraw, New York. There and to the northward they are well-developed, at, below and above sea level pages 24, 30. In Lake Flushing, they have been noted by Dr. E. Antevs[1] in the valley of the Quinnipiac River at New Haven, Connecticut (Antevs,[2] 1928, 343 varves), and reported at Fishers Island farther eastward in Long Island Sound. Logs of various wells in Brooklyn and to the eastward yield records of clay lying below the overlying sand and gravel beds.



Cross-section of the deposits in the Hudson River, developed from exploratory boring for the Pennsylvania railroad tunnels, Thirty-second Street, New York City. (After G. S. Rogers.)

In New York City blue clay was encountered in 1925, by the engineers of the New York Central Railroad in test borings on the right of way at the foot of West 14th Street, 44 to 72 feet below sea level. Blue clay has also been found in borings along the east bank of the Hudson River off West 10th Street at 98 to 162 feet, and off West Houston Street at 92 to 128 feet below sea level. The exploratory borings for the Hudson River tunnels of the Pennsylvania Railroad also revealed the presence of extensive beds of clay immediately overlying the basal till in the filled channel of the river at depths of 175–200 feet on the west side, 125–175 feet on the east side, and 200–275 feet in the east central portion page 31. Clay is also reported overlying morainal material in the bottom of the filled East River channel. Since the relation of these submerged clay deposits to the underlying till is similar to that found by the writer at Little Ferry in the Hackensack basin, he assumes that they are banded and of glacial origin.

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[1] Antevs, Ernst, 1922, "Conditions in New England During the Deposition of the Varve Clay," Amer. Geog. Soc. Research Series No. 11.

[2] Antevs, Ernst, 1928, "The Last Glaciation," Amer. Geog. Soc. Research Series, No. 17.

The correlation of the varves in the clay pits at Haverstraw, New York, has yielded 736 consecutive varves. The correlation of these varves was done by Reeds, 1927[1], 1930[2], and by Antevs, 1928[3], working independently. A total of 736 varves does not represent the entire Haverstraw section, for varves containing quicksand in the summer layers appear below the lowest varves secured. Antevs, 1928, has correlated the varves at Haverstraw, New York, with those at New Haven, Connecticut, and established their contemporaneity.

POST-GLACIAL STRATIFIED SANDS

The varved clay deposits at Mountain View in Lake Passaic are overlain by some five to ten feet of stratified sands. This is also true at Little Ferry in Lake Hackensack, where beds of sand 5 to 20 feet in thickness overlie the varved clays, page 33. At New Bridge, near the west bank of the Hackensack River, and at Oradell, gravel 5 to 20 feet in thickness appears above the clay deposits. At Haverstraw in Lake Hudson, and at points northward, beds of sand and gravel, varying in thickness from 2 to 25 feet, rest upon the varved clays, page 33. The stratified sands at Croton Point, Harmon, and Peekskill are very thick and rise to elevations a little over 100 feet, the approximate position of the shore-line of Lake Hudson at these places. They represent delta deposits made in the lake. Sandy varves about one foot in thickness, observed on Croton Point in borings made near sea level, indicate late glacial age.

Contractors, who have erected buildings on Manhattan Island, know that the southern one-third of the island and the Harlem and Dyckman sections are for the most part covered by stratified sandy deposits, which vary in thickness from a few feet to 100 feet. In the Subway excavation at 134th Street and St. Nicholas Avenue, stratified sands were exposed in January, 1926, the uppermost stratified layer being 26 feet above mean sea level. Special interest is attached to this locality because the skeleton of a horse *Equus caballus* was found by the writer, embedded in the bank, page 34. The skeleton lay on top of the highest stratified bed and in some six feet of unstratified yellowish gray clay which may have

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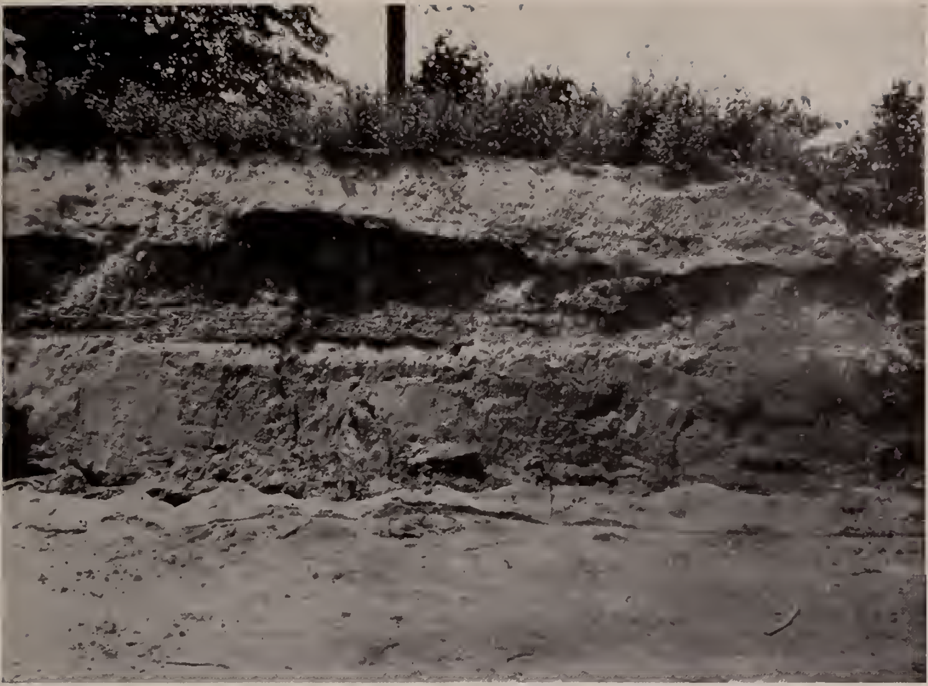
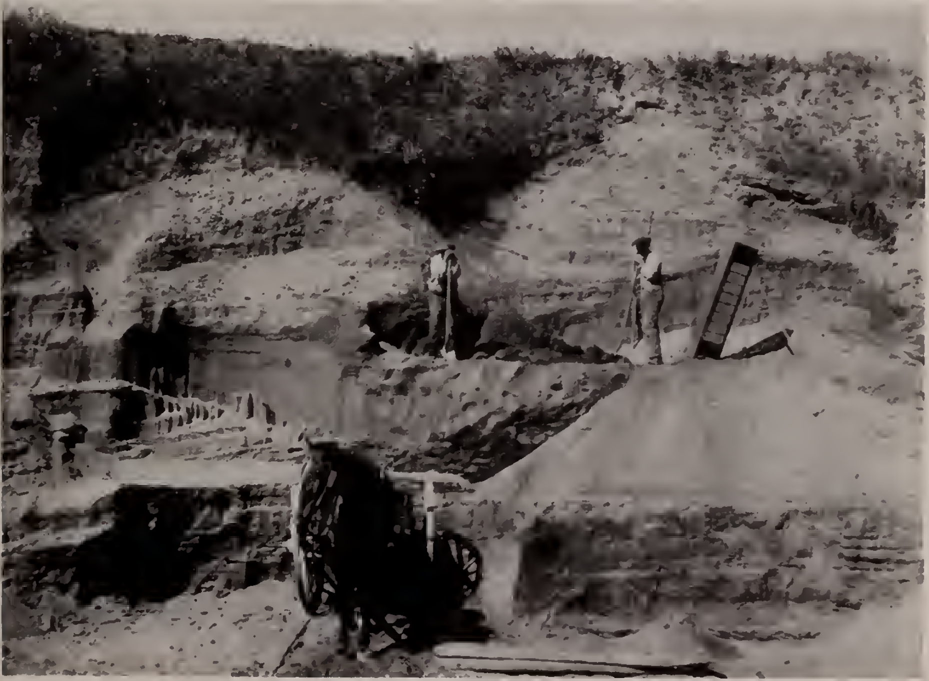
[1] Reeds, Chester A., 1928, "Varved Glacial Clays at Haverstraw, New York, Bull. Geol. Soc. Amer., Vol. 39, No. 1, pp. 217–218.

[2] Reeds, Chester A., 1930, "Weather and Glaciation, Bull. Geol. Soc. Amer., Vol. 40, pp. 597-630

[3] Antevs, Ernst, 1928, "The Last Glaciation," Amer. Geog. Soc. Research Series No. 17.



Post-glacial stratified sands, eight feet thick, overlying the varved glacial clay of Lake Hackensack. Mehrhof Brothers' clay pit, one mile south of Little Ferry, New Jersey.

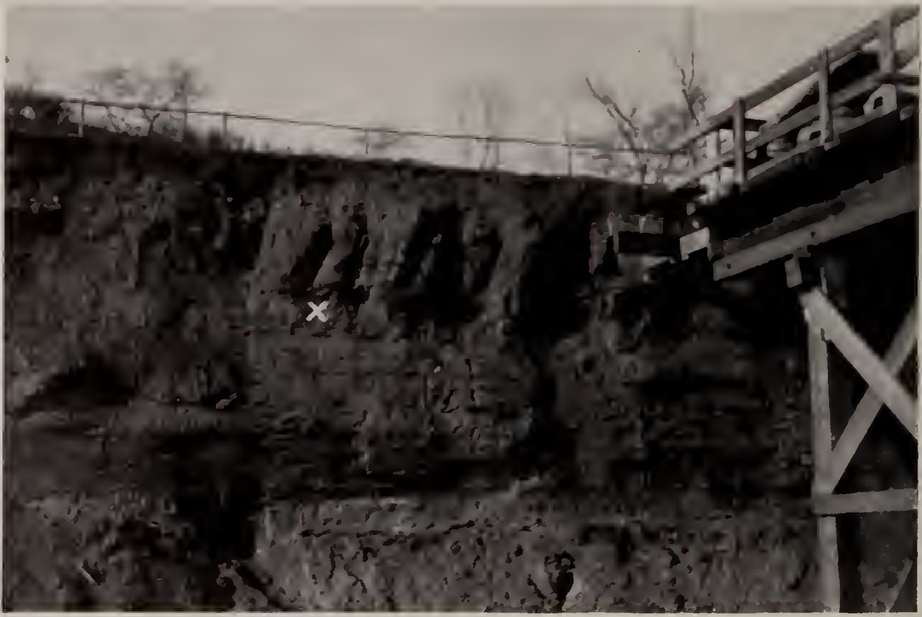


Post-glacial sand and gravel (a tributary delta deposit) overlying varved glacial clay of Lake Hudson, Hornbecker's sand-pit, West Haverstraw, New York.

Skull of horse, *Equus caballus*, found at top of the post-glacial sand. Subway excavation 134th Street and St. Nicholas Avenue, New York City.

been washed down in post-Columbian time from the hillside below the site of the College of the City of New York.

In the excavation for the New York Telephone building at Barclay, Vesey, and Washington streets, New York, bed-rock (Manhattan schist) was encountered seventy-five feet below high tide on the Hudson River side and sixty-five feet on the eastern side. Between the bed-rock and the surface, stratified gray and red sands were noticed with occasional pockets of pebbles and a few ice-transported bowlders. At a depth of 45 feet be-



Stratified post-glacial sands west bank of Subway excavation 134th Street and St. Nicholas Avenue, New York City. Skeleton of horse, *Equus caballus*, probably 300 years old, found at elevation marked X.

low high tide, a bed of peat eighteen inches in thickness was observed by the writer, interbedded in the coarse sand, and associated with it the prostrate trunks of several juniper trees, *Juniperus communis*, some ten feet in length. The bark and a number of the branches still adhered, indicating that the trees and peat had grown *in situ*. Dr. Arthur Hollick[1] of the New York Botanical Garden examined a cross-section of the trunk of one of the trees and counted some two hundred rings representing as many years for its growth. These objects indicate that during their period of development the sands containing them were at sea level. The present position indicates later subsidence of the region.

The stratified beds of sand and gravel which rest upon the varved clay deposits are, without doubt, of postglacial age. Since this is true where the clay is exposed, it is also evidently true where the clay beds are concealed from view by sands and silts, as in the Hudson River opposite 10th, 14th and 33d streets, New York, and in the East River channel. The stratified sandy deposits which occur at higher levels in Manhattan and Brooklyn are also considered to be of post-glacial age.

CONCLUSION

In this rapid survey we have considered very briefly the Relief Features, the Relief Modified by Glaciation, the Recent Shore Deposits, and the Archaeozoic, Proterozoic, Palaeozoic, Mesozoic (Triassic, Cretaceous), and Cenozoic (Pleistocene) series of rocks as represented in New York City and its vicinity. They are replete with interest but they represent only a few isolated and incomplete chapters of the geologic history of North America. The long Palaeozoic era, including the Age of Invertebrates, Age of Fishes, and Age of Amphibians, is not represented by sediments in the area of the geologic map, pages 14–15. The Jurassic and Lower Cretaceous periods, occupying the middle portion of the Mesozoic era, the Age of Reptiles, are also not represented in this district. Likewise the Tertiary series, corresponding to the Age of Mammals, appears outside the area. The Pleistocene glacial deposits, which are contemporaneous with the Age of Man, are rather fully represented but, as yet, no human remains have been found in them.

Following the retreat of the ice of the last glaciation, glacial lakes occupied the basins between the terminal moraine and the various annual positions of the ice-front. The more notable of these lakes in the vicinity of New York City were glacial lakes Passaic, Hackensack, Hudson, and

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[1] Hollick, Arthur, 1926, "Report on a Tree Trunk and Associated Lignitic Débris Excavated in Manhattan Island," *American Museum Novitates*, No. 213, pp. 1–6.

Flushing. As the ice retreated from year to year, varved glacial clays were laid down on the bottoms of these lakes. The presence of more than 2500 varves in the Hackensack valley indicates that the rate of retreat was slow, probably 60 to 100 feet per year. As the load of ice was gradually removed, the region was differentially uplifted approximately two and a quarter feet per mile from central New Jersey northward into east central Canada. This post-glacial uplift rejuvenated the streams and caused them to transport and deposit gravel, sand, and silt over the seasonally stratified beds of clay. Following the differential uplift of the land, the presence of a peat bed and tree trunks in the post-glacial sands forty-five feet below high tide in lower New York City, indicates that the region about the mouth of the Hudson River has gradually subsided. These various geologic events immediately precede the present day; how far back they go in time we can but estimate, yet the exploration and the counting of the clay varves which are in progress are affording a precise record of the annual retreat stages of the ice and the duration of the glacial lakes.

FOR THE PEOPLE

FOR EDUCATION

FOR SCIENCE